

Highway Materials Research Laboratory
132 Graham Avenue, Lexington 29, Kentucky

December 29, 1950

File No: P. 3. 1. 1.
D. 1. 7.

TO: D. V. Terrell
Director of Research

A year ago we presented to the Research Committee a first report on research dealing with "Measurements of Surface Irregularities and Riding Qualities of High Type Bituminous Pavements." That research has been carried further and along four different lines during the past year. The second progress report which is attached is an account of the additional work.

Earliest efforts this year were directed toward a new type measuring device which would overcome the limitations of a single-wheeled machine and measure all the factors that enter into riding qualities. Considerable progress was made toward equipment that would register displacements in all directions, and would not be limited to just the vertical motion recorded by a single-wheeled device such as the one used on our test last year. Our objective, of course, is to take into account forces which cause sway and jerk in vehicles passing over roads - the type of roughness which is most widespread in new pavement. Unfortunately it was necessary to suspend development of the equipment after about six months of work, even though much progress had been shown.

Two other phases of the research this year were the development of a cross section template for control on base construction, and investigation of a particular set of control devices made by the manufacturer of a bituminous pavement finisher. Finally, upon your request, rod and level measurements for variations in cross section were made early in the fall on three projects representing a spread of ten years in construction practice. As a result of all these different approaches, Mr. Field has reached a group of conclusions that show the causes of poor riding qualities and some possibilities for overcoming them. We feel that there are other things outside the scope of these studies which offer possibilities too.

Fundamentally, it appears that the highway industry has gone through a transition from conditions where hand labor could be applied rather freely to base construction, standards of workmanship in general were high, and speed or progress of the work was not exaggerated even though it was emphasized. Now we have entered a time when hand labor must be kept to an

absolute minimum, standards of workmanship have deteriorated, and speed is emphasized almost to the exclusion of everything else.

During the process of this transition there have been no basic changes in the bituminous paving machines. Hence, machines that were designed to operate over existing pavements or over bases that were laid with care for crown and grade, are not in themselves capable of laying a bituminous pavement free from surface irregularities under these new conditions. So far as contour of the finished surface is concerned, the machine is no better than the surface over which it operates unless, of course, constant attention, measurements, and screed adjustments are made. This is generally regarded as impractical, and in the opinion of many on construction jobs these manipulations cause a different type of roughness which is even more objectionable.

Inherently, then, the cause of poor riding quality lies in the base course, and theoretically it could be eliminated by returning to the practices on base construction that prevailed at the time these paving machines were first introduced. However, speed that goes with mechanization is expected, and this speed is represented in the bid prices. Since low initial cost is the determining factor, it appears that any method of securing good riding qualities - whether it is applied to the base, the surface, or the combination - must be done mechanically and it must not reduce the present rate of construction.

In my opinion, the equipment and procedures that have been available to our construction forces, and the demands that have been made on them, practically eliminated any possibility of getting the pavement to design grade and section under conditions which they have faced during the past few years. Perhaps it would be possible if there were more supervisory personnel available for assignment to these projects. It is more likely, however, that a way must be found to do it naturally with machines rather than have it forced by excessive supervision.

During the course of discussion with various men in the Central Office and in the office of the Bureau of Public Roads, several suggestions for correction have been developed. It has also been suggested that a field test project for investigating different methods be undertaken, and late last summer this idea was given tentative approval by Mr. Galbreath and the Division of Design. The object was to find out not only whether certain things could be done satisfactorily, but also whether they were so time-consuming that they would be impractical for general use. This would require a project with sections sufficiently long to give a reasonable working time in each section.

It is my recommendation that the test project be developed, and that it contain some or all of the following which have been represented in the ideas discussed heretofore:

December 29, 1950

1. Base Course: WBM finished under extreme control for grade and section (and observed mainly for the extent to which progress is retarded.)

Binder & Surface: Class I placed in the conventional manner.

2. Base Course: WBM conventional.
Binder: Class I spread with a blade grader (to gain the advantage of a long wheel base); or if this can not be done, road mix with MC.
Surface: Class I placed conventionally. If the binder is Class I the surface will be a part of the initial pavement; if it is road mix with MC the surface will be placed a year later.

3. Base Course: WBM conventional.
Binder: Class I placed full width from forms.
Surface: Class I placed full width from forms (or half-width conventional if desired.)

4. Base Course: WBM conventional.
Binder & Surface: Class I conventional.

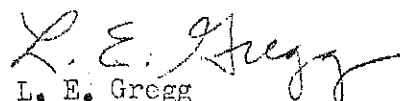
5. Base Course: Subbase of selected material and designed by recognized standards, topped by two courses of Class I base placed conventionally.
Binder & Surface: Class I conventional.

6. Base Course: Lean concrete (probably transit mix to minimize the equipment requirements)
Binder & Surface: Class I conventional.

It may be that special devices for control such as those tried on the Webster County project this year, would be available for the particular paving equipment used by the contractor, and those could be added if the contractor or manufacturer wished.

We can take some comfort in the fact that the problem of poor riding qualities is widespread and not peculiar to this state alone, nor is it a fault of either those building the jobs or those supervising them. It is essentially a sign of the times. We would be at fault, however, if we did not investigate all possibilities for overcoming the problem, and I hope that this can be done in a test project during the coming construction season.

Respectfully submitted,


L. E. Gregg

Assistant Director of Research

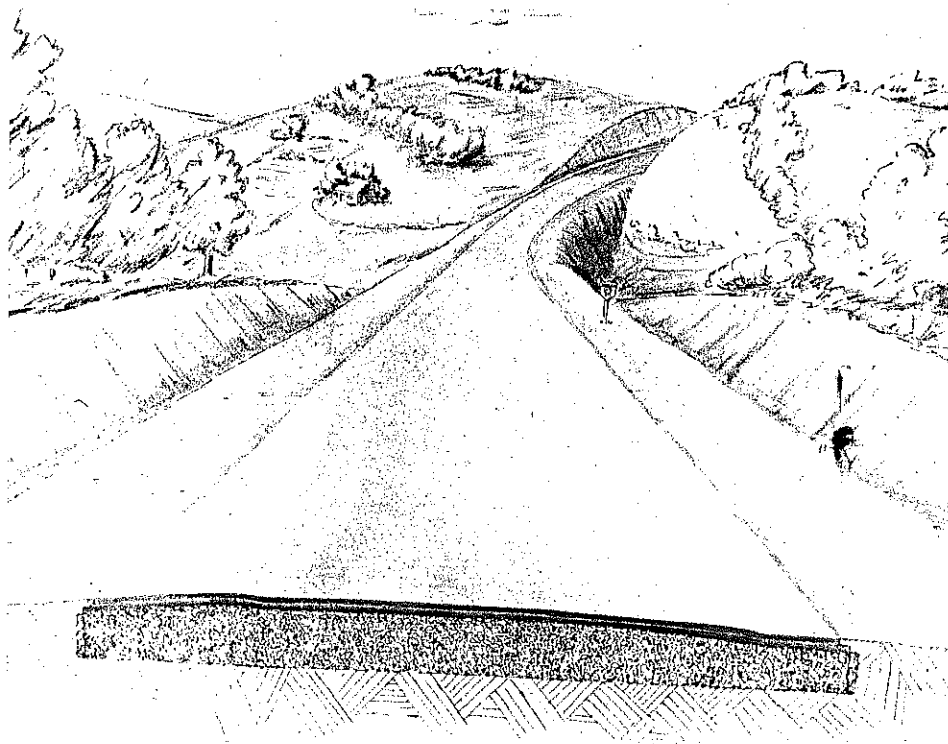
Copies to Research Committee Members
Mr. Galbreath (3)

Commonwealth of Kentucky
Department of Highways

Report No. 2

on

MEASUREMENT OF SURFACE IRREGULARITIES
AND RIDING QUALITIES OF HIGH TYPE
BITUMINOUS PAVEMENTS



by

Harvey J. Field, Jr.
Assistant Research Engineer

Highway Materials Research Laboratory
Lexington, Kentucky

December, 1950

CONTENTS

	<u>Page</u>
Introduction	1
Development of Equipment	2
Cross-Section Template	2
Barber-Greene Control Devices	5
Road Roughness Indicator	9
Field Tests and Observations	11
Cross-Section Uniformity Tests	12
Pavement Test Section	16
Results and Conclusions	24

FIGURES

<u>Figures</u>		<u>Page</u>
1	Aluminum Cross-Section Template	3
2	Schematic Drawing of the Barber-Greene Finisher	6
3	Barber-Greene Screed Control System	6
4	Barber-Greene Indicator	7
5	Rear View Barber-Greene Finisher	8
6	Slaughters-Sebree Road	15
7	Photograph of Barber-Greene Model 879-A with a Leveling Device	18
8	Aluminum Cross-Section Template on Slaughters-Sebree Road	23
9	Cross-Section and Profile F 524 (4)	25
10	Cross-Section and Profile FA 87A (3)	26
11	Cross-Section and Profile F 526 (10)	27
12	Flicker F 524 (4)	28
13	Flicker FA 87A (3)	28
14	Flicker F 526 (10)	28

INTRODUCTION

Studies of riding qualities as determined by irregularities in high type bituminous pavements were first treated in Report No. 1 on this subject in December, 1949. At that time interest was centered as much on specifications as on the causes, the thought being that specifications did not provide satisfactory tolerances to produce surfaces with good riding qualities. Specifically, tolerances over relatively short distances longitudinally were thought to be at fault.

It was found early in that work that variations in the lateral direction were causing considerable roughness but since longitudinal variations were being studied primarily, no actual measurements were made to evaluate roughness produced by non uniform cross-sections.

This year much work has been directed toward the development of a device for automatically measuring, analyzing, and recording roughness based on human comfort tolerances. Considerable effort has been spent on designing effective equipment or devices for controlling the pavement cross-section.

Logically, any irregularity, either in cross-section or profile, which could produce a change in direction and movement in the body of the car could consequently cause some discomfort to the passengers. The degree of discomfort varies with the individual and with the direction of his movement. Jacklin* proved quite conclusively that the human being can withstand greater movement up and down than he can from side to side.

* Jacklin, N. M. and Liddell, G. J., "Riding Comfort Analysis", Purdue University Engineering Experiment Station Bulletin, No. 44, 1933.

The problem still remains one of developing the necessary equipment for measuring, analyzing, and recording roughness; then from data thus obtained, designing devices which guarantee effective control of the section and profile within defined limits, and on all kinds of pavement construction.

DEVELOPMENT OF EQUIPMENT

The end point of all the research being conducted on the problem of road roughness is to produce roads with good riding qualities. It was toward that end that the development of instruments and equipment was directed, with recognition of the fact that riding qualities must be measured or defined. Accordingly equipment development fell into two categories - means for construction control and means for fundamental measurement of riding qualities. Actually one development did not come from the work of this research at all but rather from industry. So far as this project is concerned, that phase constituted a search for equipment.

Cross-Section Template

It was concluded in the work a year ago that transverse surface irregularities or deviations from the established cross-section contributed as much, if not more to the roughness characteristics than did irregularities in the longitudinal direction. As a result of this it was decided that study would be directed to the development of a cross-section template, differing from those already in existence, in that it would be

adjustable, light weight, have sufficient strength, yet fold for transportation and operation.

These features were incorporated in an Aluminum Cross-Section Template shown in Fig. 1. The device consists of a light truss capable of spanning more than 20 feet without appreciable deformation under its own weight, and a flexible, adjustable strap for describing the outline of the surface desired.

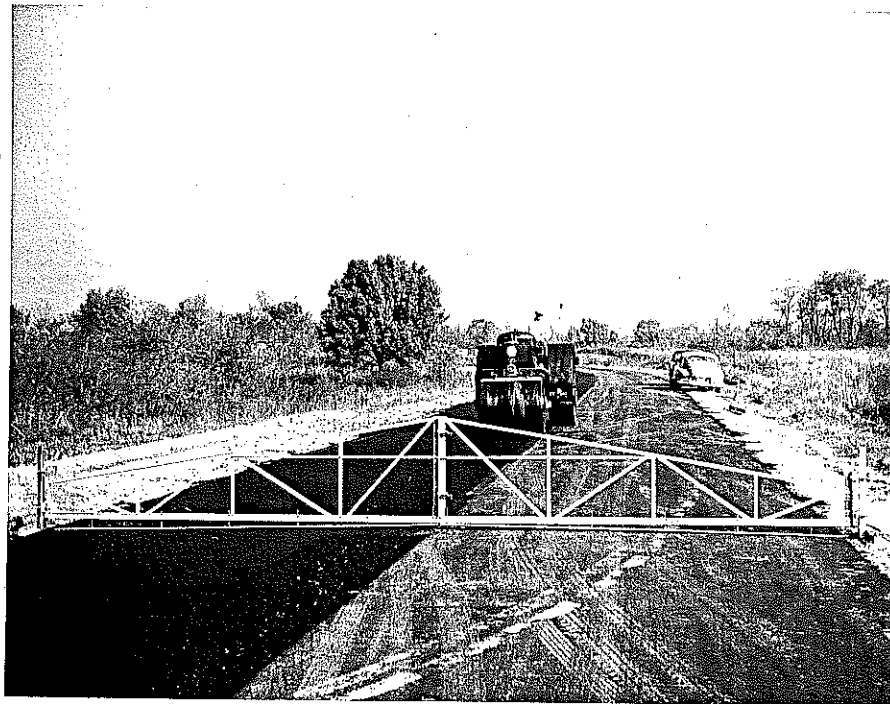


Fig. 1. Aluminum Cross-Section Template in place across a binder course overlying water bound macadam. Primarily, the template was visualized as a means for checking and controlling a section, particularly during base construction.

The truss is so designed that the lower chord forms a straight line and to this straight line the flexible strap is fastened at two-foot intervals. The flexible strap can be adjusted to

conform to any desired pavement shape; the parabolic shape for straight and level grades or the straight line from shoulder to shoulder on a curve with super elevation.

In using the template on construction the standards can be placed at the edges of the roadway and the truss lowered until the flexible strap is at the elevation of the top of the base, binder, or surface course under construction. The strap may be adjusted to the required cross-section before placing it in position. The subsequent courses can be similarly controlled by raising the truss to the proper elevation. In order to obtain pavement having the same elevation at either edge, a level (carpenters) can be placed on the lower chord of the truss for quick alignment.

On finished pavement the template can be used to check the cross-section for consistency by adjusting the flexible strap to the shape at one station then moving the truss to other stations on the pavement to check for uniformity in cross-section.

The template - designed and built by the Research Laboratory - is made entirely of aluminum, even to the bolts used on the adjusting legs. This was necessitated by the lightness requirement. The truss weighing 57 pounds, is 3 feet high at the mid-point, 22 feet-4 inches long and can be lengthened to 22 feet-10 inches. The legs at either end of the truss can be adjusted to lower the truss into any desired position.

Barber-Greene Control Devices

The Leveling Device used in conjunction with the Barber-Greene Finisher Model 879-A was developed by that company for the specific purpose of controlling crown. In order to explain the device it was felt that the Barber-Greene Finisher should be reviewed from the stand point of its component parts, their relation with each other, and their functions in the operation of the machine.

The Barber-Greene Finisher 879-A is a gasoline or diesel powered tractor-driven machine which is normally divided into two distinct units: first, the tractor unit which consists of the engine, transmission and related machinery, crawler, hoppers and feeders and the spreading screws; and second, the finisher or screed unit which has the hydraulic hoist, tamper drive, tamper bars, screed plate and heater, and the screed adjusting controls. The screed unit is independent of the tractor unit, being attached only by the arms connected at a pivot point to its tractor section. Theoretically the tractor unit travels on the road base, pulls the floating screed, and delivers the bituminous mix to produce a surface. The schematic sketch in Fig. 2 illustrates these various parts of the machine.

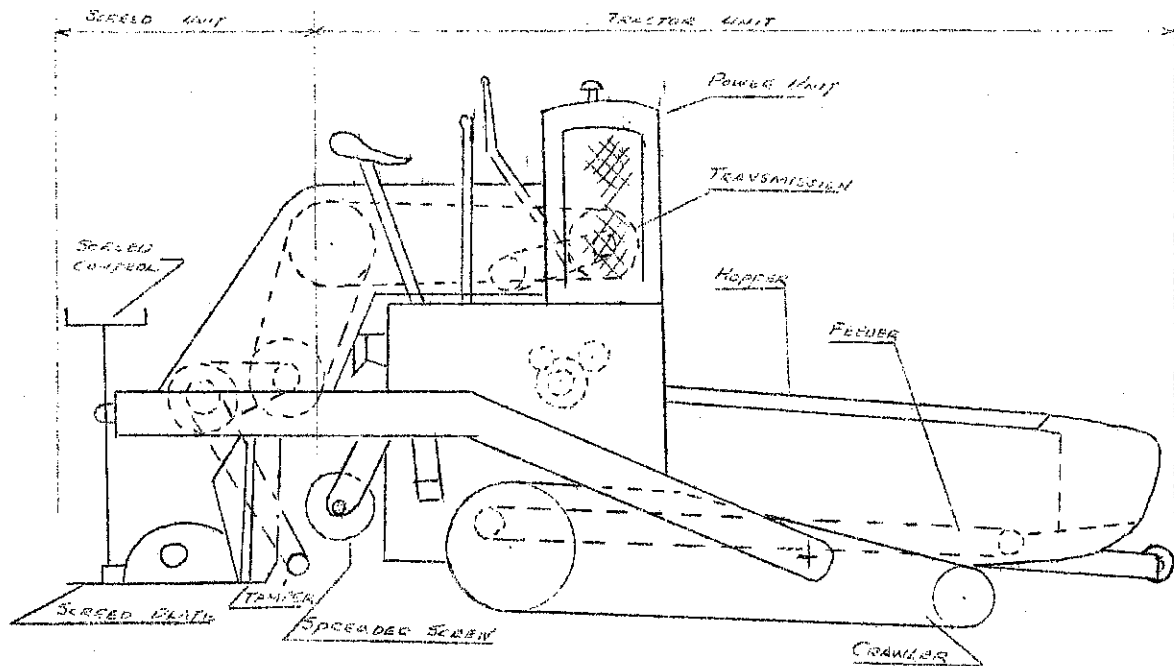


Fig. 2. Schematic Drawing of Barber-Greene Finisher

The mat thickness is controlled by moving the screed adjustment screws. To raise the screed and thicken the mat the screw is turned to the right or clock wise. What actually happens is illustrated in Fig. 3.

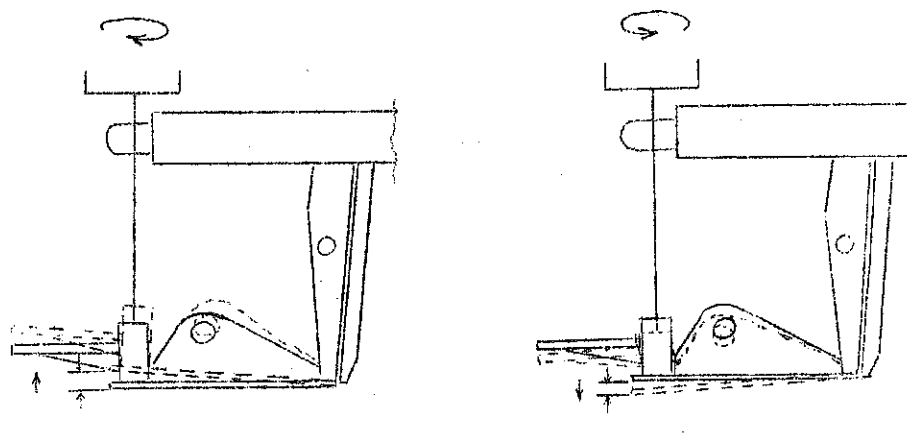


Fig. 3. Barber-Greene Screed Control System

The Barber-Greene Leveling Device is essentially a float arrangement which is attached to the frame of the screed unit of the paver. It is a metal box 8 inches wide and 10 inches tall fastened directly to the frame and having a leveling screw on one side. This box is leveled with the screed and filled with oil. A float bulb attached to an indicator arm (the point of which rests on an arc calibrated in $\frac{1}{4}$ inch increments) completes the instrument.

When the screed is tilted in either direction (from side to side) the arm, attached to the float in the oil bath, registers the degree of tilt in those units mentioned above. When the screed is level the arm is centered on the arc at zero.

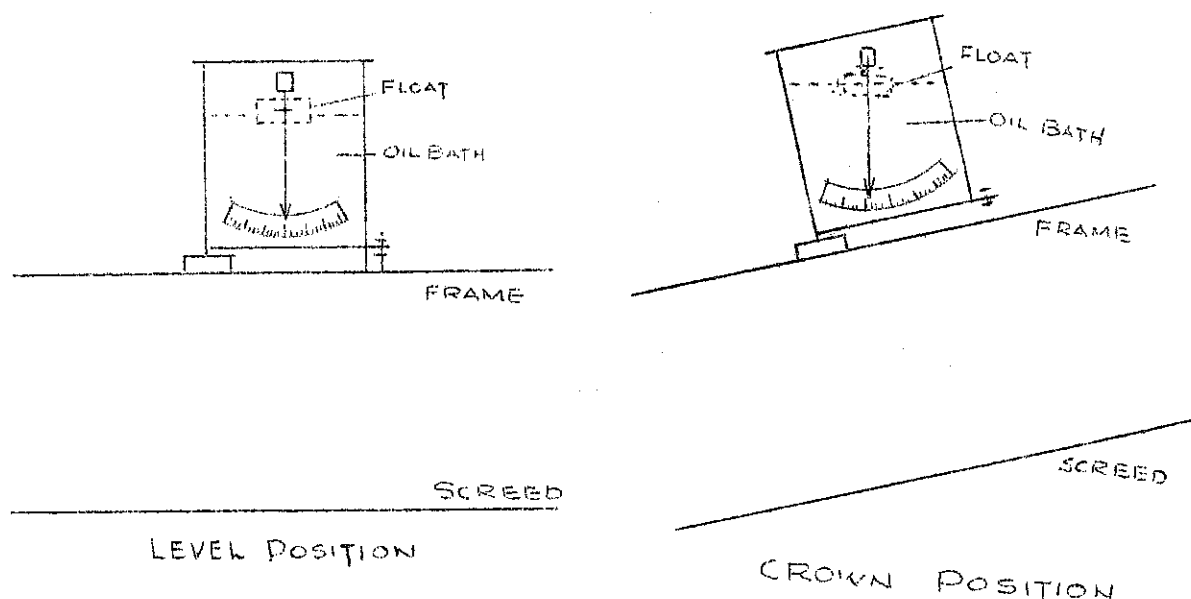


Fig. 4. Sketch Illustrating the Barber-Greene Indicator in Two Different Positions.

Since the Department Standards usually call for a $\frac{1}{4}$ -inch per foot crown on a 22-foot pavement, the screed should be adjusted so that the indicator arm reads 2-3/4 inches on the graduated arc.

Further attachments can be provided for the Finisher such as the arm and hanging plate which are fastened to the crown side of the screed unit as shown in Fig. 5. The arm and plate serve as a guide for the operator to follow when angle iron, a string line, or other lines of fixed elevation are laid on the finished course adjacent to the center line.

In order to maintain a consistent crown it is necessary to keep the plate in contact with the line of fixed elevation. This must be done by adjusting the screed when necessary. Each side of the screed must be set individually since the screed controls are separate.

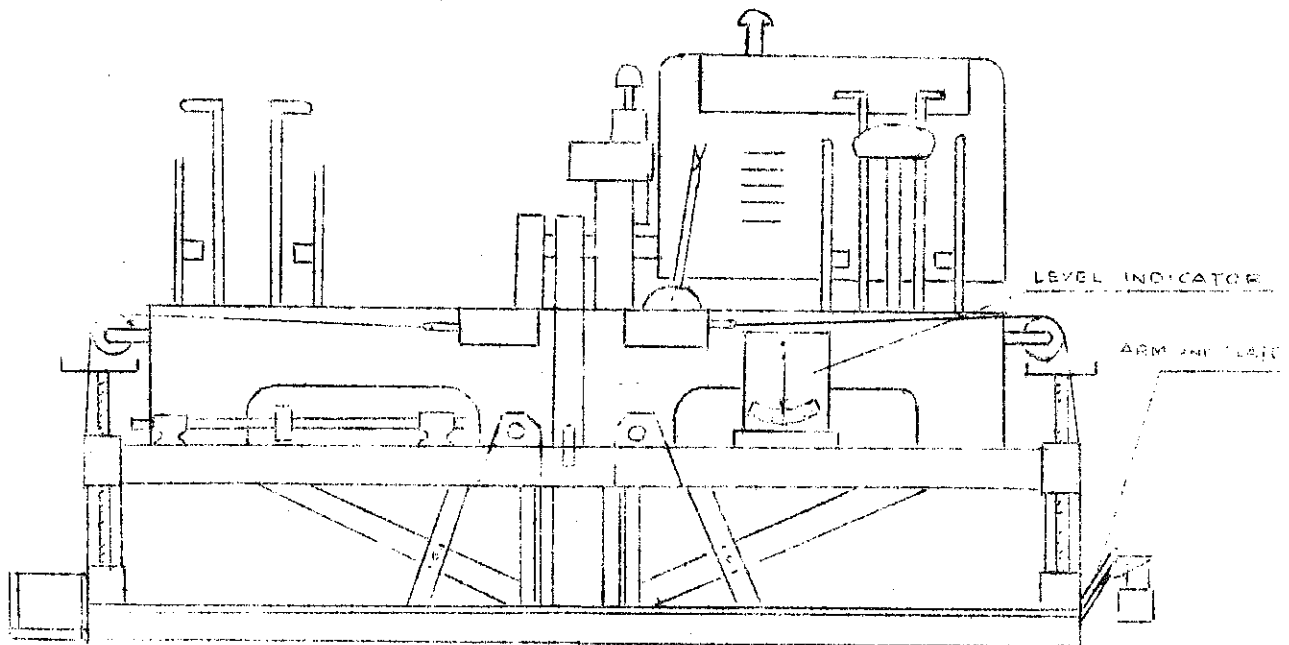


Fig. 5. Diagram Representing a Rear View of Barber-Greene Finisher Showing the Level Indicator, Arm and Plate.

Road Roughness Indicator

A major portion of this report is concerned with the actual measurement of irregularities in the pavement surface and the system which was devised for accomplishing the task. The analysis of those irregularities in terms of roughness or of their effect on human comfort cannot be made with any degree of certainty because as yet no device has been produced which can accurately measure irregularities and evaluate them in terms of human comfort.

In report No. 1 on this subject last year, mention was made of the inability of the Road Roughness Indicator, which was used in that survey, to measure variations in the transverse section simultaneously with the variations in the longitudinal direction. That apparatus had only a single wheel; therefore, it could not measure roughness as it applies to side sway.

At that time it was realized that the ultimate instrument for measuring and evaluating all factors of roughness must be sensitive to displacements in three directions simultaneously and record them in such a way as to make them readily reducible for practical use. One possible way of doing this was by means of accelerometers as sensing devices, which, when mounted on a suitable device for towing over a road, would be influenced by pavement irregularities. These instruments, aligned with one in each of the three component planes, would convert accelerations in any direction into electrical currents which would be proportional to the magnitude and frequency of the

forces caused by the pavement irregularities. With that as a basis for development, a project for investigation, design, and construction of a device for measuring riding qualities of pavement was initiated.

Designs for model studies with accelerometers of a particular design were prepared by the Aeronautical Research Laboratory at the University of Kentucky, working in cooperation with the Research Division. This required much research in literature on the subject of human comfort as well as the fundamental properties of different type of accelerometers. Following this, Schaevitz Accelerometers were purchased, and tested on a harmonic motion generating device developed by the Aeronautical Laboratory. The objective was to ascertain the response of the accelerometers in the range of frequencies and amplitudes encountered in riding reactions.

Development of suitable indicating instruments was undertaken at the same time. This work produced an analyser which would give a separate indication of the frequency and amplitude of the motion exciting the accelerometers i.e., the car's pitch, yaw, and tilt as it reacted to the travel over a road surface. Three of each of these instruments each connected to an appropriate accelerometer would then give an indication of frequency and amplitude of vibration in the three principal planes.

Another instrument which was called the "comfortmeter" was developed to work in conjunction with the above and integrate all of the motions into the resultant ultimate reaction on the passenger. This instrument has suitably marked on its indicating

dial the limits of human tolerance to vibrations as they have been determined by Janeway, Goldwin, and Jacklin individually. Thus at any given instant the indicator would show if the limits of human tolerance as defined by these workers had been approached or exceeded.

A conference with the Riding Comfort Research Committee of the Society of Automotive Engineers of which Mr. Janeway is chairman, resulted in the suggestion that possibly "jerk values" (rate of change of acceleration) should be considered in addition to simple accelerations. The instrument as developed can be converted to react to "jerk" by exciting the sensing devices with direct current rather than alternating current as in the case of acceleration measurements.

A pilot model of these instruments has been built and appears to perform satisfactorily. However, some difficulty has been encountered in maintaining proportionality and waveform reproduction simultaneously. This is felt to be an obstacle which can be overcome with some additional developmental work.

For the past few months this portion of the research has been inactive, but it is intended that development of adequate equipment for measuring all factors in road roughness be resumed as soon as possible.

FIELD TESTS AND OBSERVATIONS

The field tests conducted this year had a wide geographical spread. One project was located in Eastern Kentucky, another in the Central Blue Grass area and the third job was

located in the Western part of the state.

The three projects were completed in 1940, 1949 and 1950 respectively, and the latter project afforded a double opportunity in that the actual paving operations were observed while the construction forces were using the Barber-Greene Leveling Device.

Cross-Section Uniformity Tests

Cross-sections of finished pavement surfaces were taken, with a rod and level, in order to compare them with the designed cross-section. The purpose of the measurements was to compare shapes, not to check final elevations. The ultimate objective, of course, was to determine the differences in section which were effective in causing sway, and to eventually convert these irregularities into measured riding qualities.

Three roads were selected for measurements by level and rod over a distance of 100 feet. The first road had a Class I Type B surface, 22 feet wide, built in 1949; the second pavement was a Class I surface 20 feet wide, completed about 1940; the third road, completed in 1950, was also a Class I Type B surface. All these bituminous surfaces were placed over water bound macadam bases.

The method of selecting the 100-foot test sections was to drive over each project and attempt to locate a portion of the pavement which seemed to be fairly typical of the road in its entirety. It was of course realized that a section thus selected would be subject to opinion and for that reason no

attempt was made to evaluate the entire road based on this extremely short section. For purposes of comparison, however, each section was considered an example of its particular road.

The system followed in taking the cross-sections was to mark off a grid on the pavement surface with a piece of keel. Starting at a zero point marks were made, on either side of the pavement, every five feet longitudinally over a distance of 100 feet. The tape was then placed across the pavement, the center line established, and marks made at 2-foot intervals from the center line to the edges.

After the grid had been marked on the pavement surface, the level was set-up on the shoulder and rod readings were taken to the nearest 0.005 foot at each point marked on the pavement.

The rod readings were plotted on cross-section paper with a vertical exaggeration to better show the variations from the theoretical section. The profiles were plotted in a similar way to illustrate the irregularities in a direction parallel to the center line. Figures 9, 10, and 11, considered later as results, are plots of the sections and profiles included in the uniformity tests.

The first project, F 524 (4), Lexington-Nicholasville Road, (See Fig. 9) is located in the Central Blue Grass Area. The terrain is gently rolling and the road passes over numerous low fills and through many low to medium-depth cuts. The grade and alignment are excellent and the road has full width (10-foot) shoulders on both sides over the entire length of the project. The pavement surface which is 22-feet wide, appears to be

excellent from the standpoint of structural soundness and there are apparently no base failures of importance although there are a few prominent fill settlements which are easily noticeable. The only real negative feature of this pavement is its rather poor riding qualities noted particularly by the almost continuous side sway and occasional "galloping" motion of a car passing over the road.

The second project FA 87A (3), Clay City-Stanton Road, (see Fig. 10), is in the foot hill area of the so-called Eastern Kentucky mountain region. The pavement is 20-feet wide and has full width (5-foot) shoulders in most places except where the edge butts close to the face of a rock formation. Aside from pronounced settlements which are numerous and largely associated with carbonaceous shale deposits, the road has a uniform, neat appearance and riding qualities which have been judged good to excellent by many individual observers. Although it is not apparent to a person driving over the road, the wheel tracks have worn to such extent that they are "dished out" or rutted slightly, as shown by the elevation measurements for section uniformity.

Fig. 10, shows the cross-sectional variations to a good advantage. This section of the road, although not on a horizontal curve, is high on one side and this probably represents a transition into the curve which is about 400-feet up the road from the zero end of the 100-foot test section. Even though the measurements show a considerable variation from the design section, there seems to be some significance in the fact that

the sections are consistent in those variations.

The third road tested by the rod and level method was the project F 526 (10), Slaughters-Sebree Road, which is located in the Western part of the state. Along this particular road the terrain closely resembles that in the Blue Grass Area, but the formations are greatly different. The Slaughters-Sebree Road lies in the western coal field region, where the formations are weak sandstones and shales, and the soil mantel is heavier than in the Blue Grass. This is partly because of the contrast in residual soils, and partly because of the cover of windblown soils which are important in some localities. So far as the

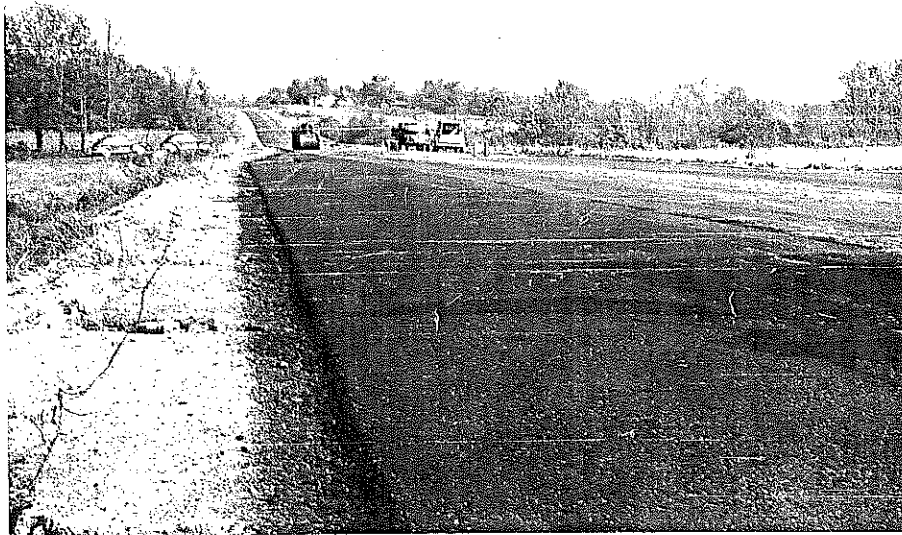


Fig. 6. Webster County Project F 526 (10) Slaughters-Sebree Road looking north toward the Test Section which begins at the point where the roller is standing and extends northward approximately one mile.

road itself is concerned, the grade and alignment are excellent and the section is modern throughout, with the 22-foot pavement being flanked on both sides by shoulders 8-feet in width.

The 100-foot uniformity test section on the Slaughters-Sebree project was a portion of a test strip almost one mile in length which was being investigated for a finishing control method, as described later in this report. Even with these efforts to control the crown, there were variations in section which are shown in Fig. 11.

Pavement Test Section

The conclusion that a certain amount of roughness in pavement is caused by variations in the crown or at least failure to maintain a constant crown led to investigations in the paving equipment field. The Barber-Greene Company was one of the manufacturers which expressed concern over pavement irregularities and an interest in equipment which might overcome them in finishing operations. This company requested an opportunity to apply its so-called leveling device on a test section where the services of company employees could be utilized in the operation of the equipment.

Arrangements were made with the Division of Construction whereby about a mile of Project F 526 (10), the Slaughters-Sebree Road in Webster County, could be used as the test location. This project was under contract with the State Contracting Company, Inc., who were using a Barber-Greene Finisher, Model 879-A which could be adapted to perform the operations necessary

in laying the pavement.

Some pertinent features of the pavement design for the project are as follows:

Insulation: 2" compacted aggregate; 50% crushed Ls.
No. 5 and 50% screening No. 10.

Base: 4" compacted WB. Macadam; crushed Ls.
No. 1 and Screenings No. 10.
4" compacted WB. Macadam; crushed Ls.
No. 2 and Screenings No. 10.

Prime: 0.25 gal. per sq. yd. R.T.-2
Binder: 150 lb. per sq. yd. Class I (PAC-5)
Surface: 150 lb. per sq. yd. Class I, Type B
(PAC-5)

Total depth - 13" approximately
Total length of project - 4.739 miles

The insulation and waterbound macadam base courses had been completed quite some time before the bituminous paving and the test observations were started.

Because of delays caused by the plant set-up, paving did not begin until Friday, October 20. The first load arrived from the plant at about 8:00 a.m. and the binder course was started at Station 250 + 00 on the west lane going south toward Slaughters. The first days run was rather short as usual, because of the time required to get equipment operating properly and material flowing smoothly to the job.

On Saturday, October 21, the paver returned to Station 250 + 00 and laid the east lane up to Station 201 + 75. On Monday, October 23, the paver was returned to the place where Friday's work was stopped in the west lane, and material was laid up to Station 200 + 75 at noon.

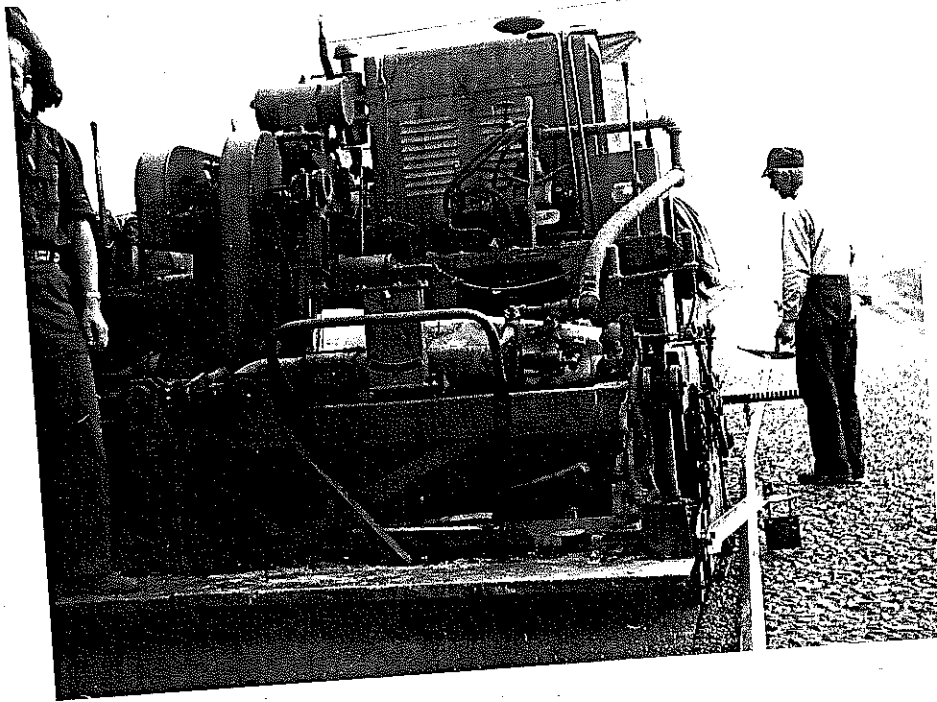


Fig. 7. Rear View of the Barber-Greene Finisher Model 879-A with a Leveling Device. The angles shown at the right side of the machine were being placed at the time the photograph was taken. Difficulties were encountered in the placement due to the lack of trained personnel. Also, the limitations of placing such a datum line by eye and bringing it to elevation by shims are apparent. Setting of such a datum to grade with a level and rod would be much more accurate and dependable.

The metal plate suspended from the arm at the right side of the Finisher should ride just above the angle and in the event of irregularities in the base course causing tilting of the entire machine, adjustments must be made by the screed adjustment screw on the right side to keep the plate in approximate contact with the angles. This necessitates a comparable adjustment in the left adjustment screw to maintain crown. More consistency could be obtained if both screws could be adjusted simultaneously.

It was decided that the test mile would start at Station 201 + 00, at which point the Barber-Greene Leveling Device was placed in operation under the supervision of personnel from the company. All the binder laid up to this point had been placed according to standard procedures and appeared to be well done although the irregularities in the water bound base were noticeably reflected in the binder course by variations in the crown. The crown was actually checked by instruments at several points.

When the Leveling Device was put into operation the procedures were as follows: angle iron (2-inch equal leg) was laid adjacent and parallel to the center line in the direction of paving, for a distance of about 200-feet. After the sections of angle were placed they were aligned and shimmed to elevation by eye. Actually greater accuracy would have been obtained by setting the angles to elevation and alignment by instrument. The distance from the center line at which the angles were placed was governed by the pavement width and the distance from the side of the machine to the "trailing" plate. Fig. 7, page 18, shows clearly the set-up as it was used, although at the time of this photograph the angle line ahead was just being established. After the angles were placed, the finishing machine in the normal operating position was guided by the operator so that the plate rode on the angles. An irregularity in the previous course would cause the tractor unit to tilt and the plate riding the angle would swing free or drag. Then the screed operator would quickly adjust the screed on the side adjacent to the center line to bring the plate back to proper position.

In order to retain the correct crown it was also necessary to adjust the opposite screed screw to keep the Indicator (see Fig. 4, page 7) on the correct readings.

As soon as a section of angle was passed in the paving operation, this section was picked up, placed at the head of the line, and brought to proper elevation and alignment.

The test mile included the following, in succession from north to south: about 300-feet of straight and level grade; a hill (plus grade); a 4° curve with super elevation (no widening on curve); a spiral with no super elevation; a hill (negative grade); and about 800-feet of straight and level grade. The section ended about 200-feet in a widening area where Ky 147 turns off toward Owensboro.

The test section required 2 $\frac{1}{2}$ days of work apparently slowing construction slightly. This retarding of the work was not caused entirely by the special operating procedures, but at least partly by difficulties at the plant.

Placement of the binder in the test section was completed on October 25, at Station 150 + 75 just 255-feet short of 1.0 mile. There were 1130.5 tons of material used on this portion, as opposed to a calculated quantity of 942.77 tons needed to satisfy the 150 lb. treatment. This resulted in an overrun of 19.9 per cent, above the design figure.

On Monday, November 6, 1950 the contractor commenced laying the surface course on the test section, starting at Station 201 + 00 (west lane). Pavement was laid to Station 186 + 00 by the end of the working day. On the following day

pavement was laid from Station 201 + 00 (east lane) to Station 154 + 50. Because of inclement weather the contractor was unable to work for the remainder of the usual working week. Sunday, November 12, 1950, the contractor was granted permission by the District Office to lay pavement. This was started at 11:00 AM, and the surface course was laid from Station 186 (west lane) to the end of the test section at Station 150 + 75. The surface was completed on Monday, November 13, 1950, by laying the course from Station 154 + 50 (east lane) to Station 150 + 75.

A total of 915.0 tons was used and theoretically 922.0 tons should have been laid, therefore the surface course under-ran by 0.76 percent.

Unfortunately on the work done Sunday, November 12, 1950, none of the so called special leveling methods was used, so the test section actually had control applied only on the binder. The placement of the surface course was not observed by any representative from the Research Laboratory, nor by anyone from the Barber-Greene Company.

This project also presented the Research Laboratory an excellent opportunity to apply the Aluminum Cross-Section Template, a device that can be adjusted to fit any crown and can also be used at any stage of the construction, to control and check the cross-section.

A number of visitors at the project expressed interest in the device and some suggestions were made for improvement such

as increasing the length of the standard so that the template could be actually laid across the blue tops on either side of the road, thus establishing exact control. It was recognized that the device could be applied to best advantage on base course construction, even though it was not actually used for that purpose on this project.

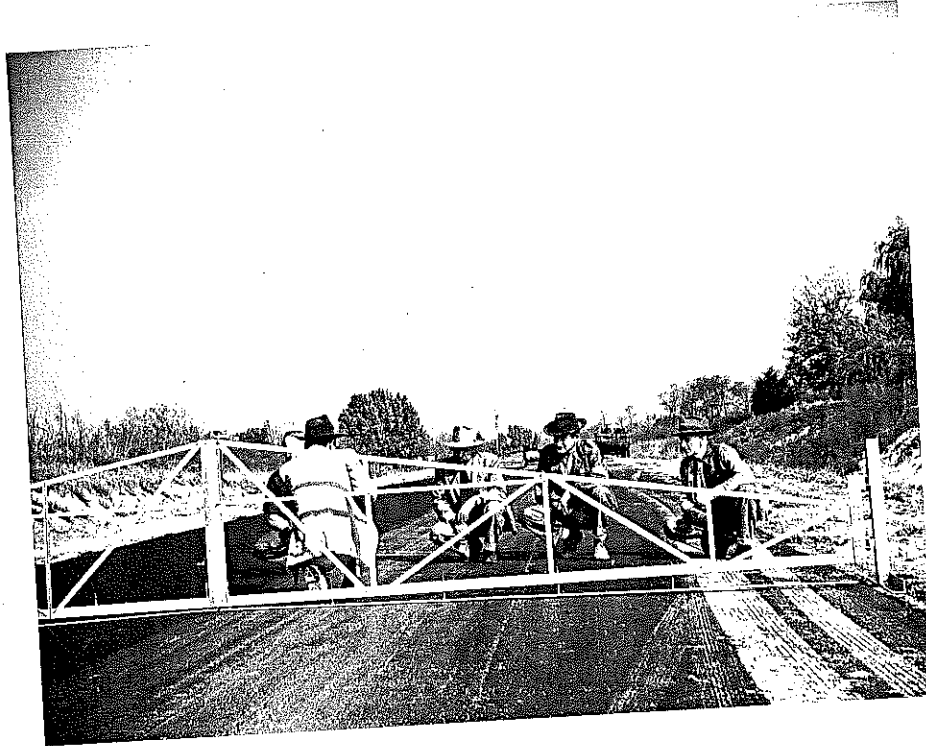


Fig. 8. The Aluminum Cross-Section Template in operating position on the Slaughters-Sebree Road. The test section on this project was not started until after the water-bound macadam base had been completed, therefore there was no possibility of evaluating the device for control during base construction - the principal objective of its development. The ease of handling, general conformity with construction conditions, and sturdiness could be judged very well. Also, several valuable suggestions on its use were developed by engineering personnel on the project and those visiting it.

RESULTS AND CONCLUSIONS

The results of cross-section uniformity measurements on the three separate projects are shown in Figs. 9, 10 and 11. Irregularities in the section are magnified of course, since the vertical scale is magnified ten times that in the horizontal direction. Even greater magnification is used in the "flickers" representing these same sections in Figs. 12, 13 and 14. The purpose of the flickers is to demonstrate in an exaggerated way the relative motion that could be induced in a car as it passes from one station to another five feet away and throughout the entire 100-foot section in each case.

Actual displacement of a car, or more important still the actual effect on passengers in the car, can only be inferred from the cross-section measurements. True effects of these irregularities could be established only by the passage of a standard vehicle carrying sensing devices such as accelerometers and recording instruments. The abbreviated laboratory studies with accelerometers gave reasonable assurance that such a device could be developed, although the conditions under which they were studied were not correlated with any conditions on the road.

Fig. 9, illustrates the irregularities as they occurred in the 100-foot test section on Project F 524 (4), Lexington-Nicholasville Road. Each faint line on the drawing is the design section with respect to the measured center line elevation at that station. Comparison between the actual and theoretical

sections shows that the actual crowns are almost invariably low. Changes in section within the length of wheel-base on an average car are apparent. The entire 100-foot section would be passed in 2 seconds by a car traveling about 35 miles per hour. Irregularities in crown such as these are the cause of poor riding qualities characterized by vehicle sway.

Fig. 10, a plot of the cross-section taken on Project FA 87A (3), Clay City-Stanton Road, shows the tendency toward depressed wheel tracks which has occurred on this 10-year old pavement and also the fact that it is tilted to one side. Apparently this tilt and rather flat crown is caused at least partially by the curve a short distance beyond the test section. Even with these irregularities, there is a consistency of section throughout, which is undoubtedly the reason that this road has been generally considered a smooth-riding highway. In contrast with the conditions shown in Fig. 9, this road has no sudden or abrupt changes in section to cause vehicle sway.

The uniformity test section on Project F 526 (10), Slaughters-Sebree Road (Fig. 11), has a very consistant crown on one side and to that extent follows closely the theoretical shape. The other side is comparatively flat. Differences in elevation between the two edges is as great as 0.2-foot - such as at line 100. There is no significance attached to the difference between lanes so far as riding qualities are concerned, since traffic in either direction is generally confined to a single lane. However, it is significant that these discrepancies from design section existed despite the fact that this 100-foot

uniformity section was a part of the one-mile pavement control test section.

As a result of these measurements and the observations which have gone with them, the following conclusions have been drawn:

1. The underlying cause of surface irregularities in high type flexible pavements is the water-bound macadam base.

2. Although the irregularities almost invariably came as deviations from the design section, poor riding qualities expressed by sway in passing vehicle are brought about by a lack of consistency in the sections rather than the departure from design section. In other words, departure from design section does not cause roughness so long as the section is consistent.

3. If these irregularities are to be eliminated in the bituminous portion of the pavement, emphasis must be placed on uniformity in pavement elevations rather than uniformity of mat thickness.

4. The conventional bituminous pavers, finishers, or spreaders inherently lack features necessary for control of section unless the base upon which the machine operates is true to section and grade.

5. The Barber-Greene leveling devices offer some promise of correction with the bituminous mix. However, the advantages of this equipment can not be fully utilized unless:

- a. The datum line for reference with the trailing plate is set to a specific grade with an instrument and rod; and

- b. the adjustments in screed settings on both sides of the machine are made simultaneously.

Even with these provisions assured, the efficiency of the control devices would be dependent entirely upon the alertness and care of individuals making the screed adjustments.

6. If elimination of irregularities with the bituminous mix is undertaken, quantities in excess of those specified for a uniform depth of treatment will be required. In brief, there will be an overrun in quantities unless allowance for additional material is made in the design.

7. Probably the amount of overrun could be kept much lower than 20 per cent (as recorded on the Webster County Project) if variation in edge thicknesses from $1\frac{1}{4}$ inches per course down to a minimum of $\frac{1}{2}$ or $\frac{3}{4}$ inch were permitted particularly for the binder course. This would avoid excessive depths of bituminous mix near the center where adjustments are necessary to keep proper crown. Such an allowance would not impair the structural value of the pavement at its edge, assuming that the depth of base course is adequate.

8. Design standards providing for $\frac{1}{4}$ inch per foot crown in bituminous pavements are excessive and probably unnecessary. This is based on the observation that such crown is seldom obtained yet surface run-off on the pavements seems to be satisfactory. A crown of $\frac{1}{8}$ inch per foot - as specified for other high-type pavements - should be adequate and perhaps easier to accomplish in paving operation.

9. The Aluminum Template should be a valuable means for control of section on base construction, provided it can be operated off blue tops or something else closely spaced (perhaps at 20-foot intervals) and set to specific elevations that are correlated with the finished pavement grade.